Unbound states in ^{11}Be

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ABSTRACT : Charge exchange on a target of ^{11}B will be used to populate unbound excited states in ^{11}Be. For states above the threshold for decay into the ^{10}Be (2^+_1;3.37 MeV) first excited state, the relative branching to the 2^+_1 and to the 0^+ ground state will be measured, to give information about the spin and structure of the parent states. For decays to the ground state, the breakup correlation will be analysed to identify the single angular momentum that can contribute. The measurements will employ the MEGHA array in its hybrid-plus-strip configuration. These measurements are envisaged as part of a programme to study halo and halo-related nuclei (^{11}Be, ^{10}Be, ^{9}B, ^{8}B, ^{17}Ne, ...), complementing our programme at GANIL. The data from this experiment are planned to form a part of an EPSRC-funded Ph.D. thesis at Surrey.

Introduction

The lowest two levels of ^{11}Be are well known to have a single neutron halo structure, and the higher excited states are important for testing models of the halo structure of ^{11}Be. These theoretical models [1] have been extended to describe the more neutron rich Be isotopes also, such as ^{12}Be [2] and the Borromean system ^{14}Be. However, even in ^{11}Be the properties of the unbound states are poorly known, and spin/parity assignmants are disputed [3, 4, 5]. An additional interest in ^{11}Be states arises from their population in the β–decay of ^{11}Li [6], as their properties then give information about the Borromean ground state of ^{11}Li itself [4].

We have studied the neutron rich isotopes of Be in three experiments at GANIL. Recently, the ground state breakup of ^{14}Be was probed in the reactions of a secondary ^{14}Be beam with carbon and lead targets [7]. This is the heaviest Borromean system whose breakup has been studied. This study is expected also to provide data on levels in ^{13}Be, which will help in refining the theoretical models. In a new proposal [8] we included a further search for ^{13}Be states. Also very recently, we studied cluster breakup from states in ^{12}Be following inelastic excitation of beam particles, and found the first clear evidence for cluster structure in ^{12}Be [9]. Using stable beams and targets, it is of course impossible to reach the extremes of neutron richness, but the first halo nucleus in the isotopic sequence (i.e. ^{11}Be) is accessible and is well suited to experiments using the MEGHA array.

The low-lying level scheme of ^{11}Be is shown in fig.1. For the 3.4 MeV state, the angular momentum of the final neutron is not known, and for the higher levels there is only one firm spin assignment. Some limited information on the branchings for neutron decay is available from β–decay, for levels between 4 and 8 MeV [6].

Using stable beams, the spectroscopy of ^{11}Be has been studied by the following reactions: ^{9}Be(t,p)^{11}Be (Q-value = -1.166 MeV) [10, 11], ^{10}Be(d,p)^{11}Be (Q = -1.720 MeV) [12], ^{12}C(^{7}Li,^{8}B)^{11}Be (Q = -28.187 MeV) [13, 14], ^{13}C(^{6}Li,^{8}B)^{11}Be

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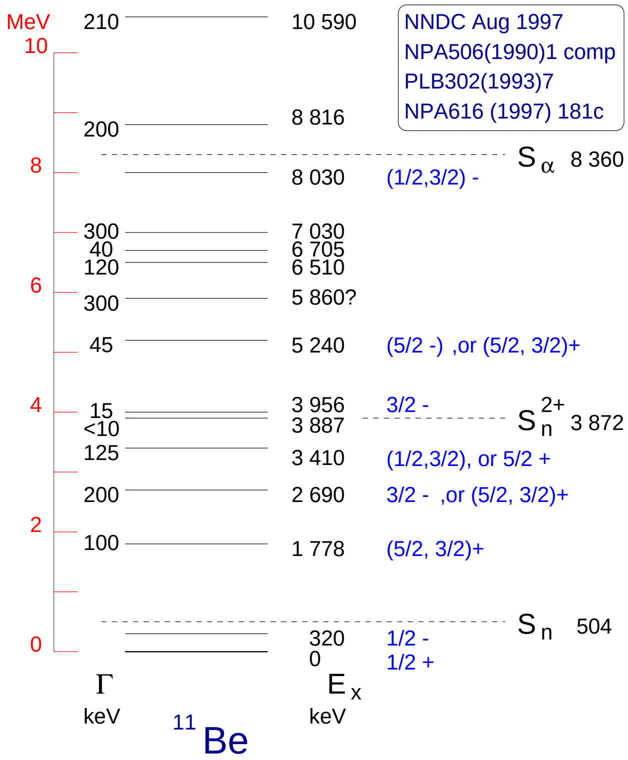
(Q = −25.884 MeV) [13, 15], ^{11}B (d,^{2}He) ^{11}Be (Q = −25.884 MeV) [16]. The present experiment will employ the reaction ^{11}B (^{7}Li,^{7}Be) ^{11}Be at 60 MeV (Q = −12.367 MeV), which has not previously been studied.

Figure 1: Level scheme of ^{11}Be.

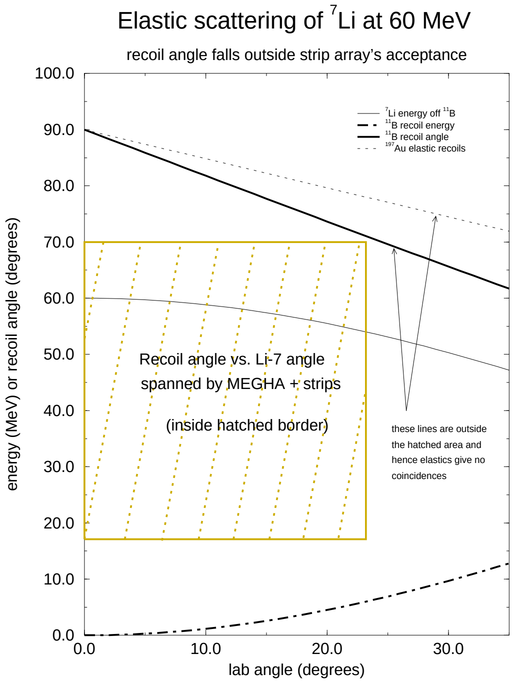


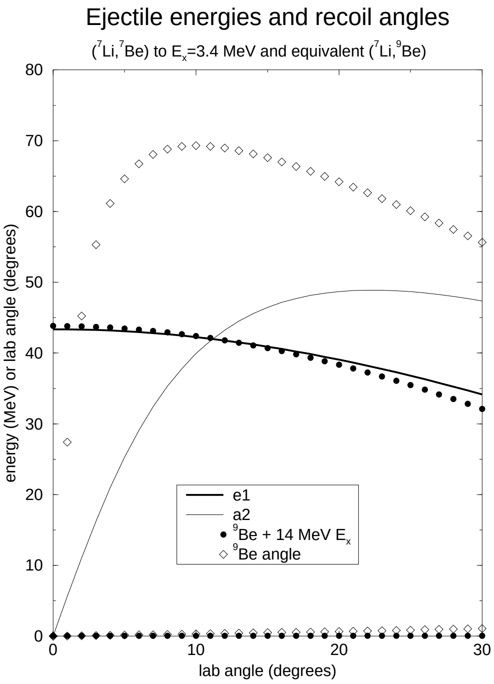
Experiment

The measurement will employ the MEGHA array in the hybrid-plus-strip configuration, in which the two sides of the beam direction are instrumented with gas-Si-CsI hybrids and silicon strip PSD's respectively. The hybrid detectors span the range 2.5° to 25° relative to the beam direction. The strip detectors can be instrumented to cover the range 17° to 78° on the opposite side. The hybrids will be used to record the ^{7}Be ions, and the strip detectors will record the coincident ^{10}Be breakups from the recoiling ^{11}Be nuclei. The trigger for the data acquisition will require a coincidence between a hybrid and a strip detector. The dominant counting rate in the hybrids will be elastic scattering, and this will be eliminated from the trigger by the coincidence requirement. Fig.2 illustrates the effectiveness of this technique: the hybrids can detect out to 25°, but the corresponding recoils are at angles between 70° and 90° and we can choose not to cover this range with strip detectors.

For the (^{7}Li,^{7}Be) reaction of interest, the recoiling ^{11}Be emerges from the collision at angles forward of 50° (see fig.3). For ^{7}Be angles between 2.5° and 25°, the recoils fall within the range spanned by the strip detectors. Since MEGHA can provide Z identification but no A identification, it is important to be able to distinguish between reactions producing ^{7}Be and those producing other Be isotopes. This is assisted by

Figure 2: and Figure 3: — Fig. 1 (left) shows the coincidence detector settings to eliminate elastic events; Fig. 2 (right) shows kinematics calculations of recoil angles.



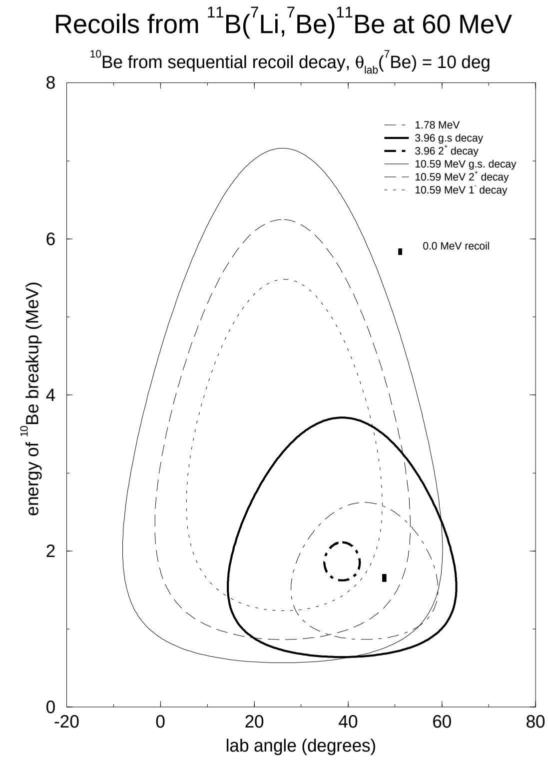


the fact that ^{8}Be, and the isotopes ^{6}Be and lighter, are all unbound. The most likely ambiguity when a Be is recorded in a hybrid is between ^{7}Be and ^{9}Be. Fig.3 shows the locus of points for ^{9}Be ejectiles at the same energy as ^{7}Be. The kinematic fall-off is not sufficiently different to distinguish the isotopes, but the mass has a significant effect on the recoil. Firstly, the recoil angle is shifted by at least 15° relative to the recoils of interest. Secondly, to achieve a match for the ejectile energy, the recoil must carry an extra 14 MeV of excitation. Thus, its breakup products will be distributed over a much wider range of angles, and will show markedly different energy-angle systematics.

The energy-angle systematics for breakup products from the sequential decay $^{11}\mathrm{Be}^* \rightarrow\ ^{10}\mathrm{Be}+n$ are shown in fig.4. These calculations are for ^{7}Be ejectiles detected at 10°. The breakups shift in angle, and spread out over a wider range of angles, as the excitation energy in ^{11}Be increases. For purposes of display, the calculations are shown for coplanar breakup only, whereas the breakup obviously takes place in three dimensions. The reconstruction of the data can take three dimensional breakup into account. Then, the breakup opening angle can be checked for consistency with the energy and angle of the ejectile ^{7}Be. It is clear that the kinematic coincidence requirement can identify the reaction products of interest with a high selectivity.

The beam will be ^{7}Li at 60 MeV, provided by the 14UD accelerator operating at 15 MV. The energy is not critical, and for example 50 MeV could also be used if necessary, but the higher energy should give a higher counting rate. The ^{7}Be ejectiles will be stopped in the silicon component of the MEGHA hybrids; the most energetic elastic ^{7}Li ions and some lighter ions will pass through to the CsI element. Using the hybrids' combination of sub-millimetre position resolution with energy resolution of around 100 keV, the excitation energy resolution will be ~100 keV. For the recoil breakups, the energy loss in escaping from the target will be important, and for this

Figure 4: Energy-angle systematics for ^{10}Be breakup products.



reason the target thickness will be limited to $50\mu g/cm^2$. This is expected to give no more than 150 keV spread in energy resolution for coincident ^{10}Be ions. The strip detectors have been proven to give good position resolution at energies as low as a few MeV, and should certainly give sub-millimetre resolution in the (horizontal) strip direction. Thus, a reconstructed ^{11}Be excitation of several hundred keV should be achievable (for comparison with that deduced from the ^{7}Be ejectile), or equivalently the excitation energy of the daughter ^{10}Be can be deduced (the first and second excited states in ^{10}Be are at 3.37 and 5.96 MeV).

The coincidence counting efficiency is affected mainly by the size of the breakup cone for the sequential process $^{11}\mathrm{Be}^* \rightarrow\ ^{10}\mathrm{Be}+n$ and by the out-of-plane effects. The breakup cones have half-angles of up to 30 degrees in the laboratory frame (fig. 4), whereas the individual strip detectors subtend between 16° and 20° and span from 17° to 70°. Also, the ^{7}Be ejectile has a velocity of around β=11% and the recoil has typically β=1.8% and 11/7 times the ejectile mass. This enhances the out-of-plane angle for the recoil relative to the ejectile by a factor of approximately 4, so that some recoils would miss the strip detectors. However, some of these events will be retrieved because the breakup cone extends back into the detector range. In combination, it is estimated that the recoil coincidence efficiency will be ~50% on average.

As discussed above, the energy resolution requirements indicate that a target thickness of no more than $50\mu g/cm^2$ is preferred. The $^{7}\mathrm{Li}^{3+}$ beam intensity must be limited so that the elastic scattering does not saturate the MEGHA hybrid detectors. Each individual detector subtends approximately 7 msr at the target, with the most forward detector centred at 5°. The next most forward detector, mounted in the outer module, is centred near 12°. For these two detectors we estimate 2000 counts/enA and 150 counts/enA respectively. Thus, the beam current is limited to either 5 enA or 65 enA, depending on whether the innermost detectors are employed. The innermost detectors span the useful centre-of-mass angles of 5–15°, so we have assumed 5 enA of $^{7}Li^{3+}$ beam. It may be possible to use slightly more beam if the inner module is instrumented with only the corner detectors.

Beam Time Request

From a previous study of ^{36}S (^{7}Li,^{7}Be) at similar energies [17], it is reasonable to assume a cross section of 0.1 mb/sr at the forward angles, for low-lying favoured states. This is a factor of ten above the cross section measured for (d,^{2}He) [16]. Assuming 0.1 mb/sr and 5 enA, for a single detector ($\Delta\Omega = 7$ msr) the counting rate is 570 counts per eight-hour shift, per state in ^{11}Be. However, for some higher lying states we can reasonably suppose a cross section reduced by an order of magnitude, and in addition the coincidence efficiency of 50% must be included. This gives ~30 coincidence counts per shift, per state, for the weaker states of interest. It is estimated that 250 counts (above background) will be needed as a minimum, in order to extract accurate excitation/decay energies and angular correlation information. Thus, nine shifts of beam are requested. In addition, two shifts of running on a carbon target will be required for background estimation. (Although the targets will be self-supporting ^{11}B , carbon contamination is possible, particularly with gas-filled detectors deployed close to the target.) Finally, it is estimated that one shift will be required to focus the beam down the line to the MEGHA target position, and that a further three shifts are required for detector calibrations, gas-in/gas-out runs, etc., making a total of 15 shifts, or 5 days. The beam time request is summarised in the table.

Table 1: Summary of beam time request

Measurement	Beam	Energy	Target	Shifts
{ ion source beam focussing }	^{7}Li	60 MeV	none	1
calibrations	"	"	^{11}B,Au,C	3
^{11}Be states	"	"	^{11}B	9
background	"	"	C	2
TOTAL				15

Summary

This measurement should add significantly to the present sparse knowledge of ^{11}Be 's structure. The experiment utilises the large geometrical coverage and high detector granularity afforded by the MEGHA array and its multichannel electronics. The experience gained in this work should allow further halo-related experiments to be planned. The data from this work are planned to form the basis for thesis work by an EPSRC-funded Ph.D. student (K.L. Jones) at Surrey, to complement her analysis of GANIL data for neutron-rich B and Be isotopes.

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